AN INVESTIGATION INTO THE EQUIPMENT, TECHNIQUES, AND PROBLEMS ASSOCIATED WITH UNDERWATER CINEMATOGRAPHY

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AN INVESTIGATION INTO THE EQUIPMENT, TECHNIQUES, AND PROBLEMS ASSOCIATED WITH UNDERWATER CINEMATOGRAPHY

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CHAPTER I

INTRODUCTION

THE PROBLEM AND ITS SCOPE

As the reader might surmise, underwater cinematography is the technique of filming motion pictures below the surface of the water, and, since three-fourths of the earth's surface is covered by water, this offers a vast new and exciting world to record on film.

Submarine photography is nothing new, but with the recent advancement in technique and equipment, its long-recognized potentialities are today being realized. Naturally, underwater photography introduces certain problems that are quite foreign to surface photography, but through the efficient design and use of the underwater camera, these difficulties can be minimized and excellent results can be achieved.

The future for underwater cinematography is extremely bright, not only in the entertainment and scientific fields, but also in the production of educational films, navy training films, salvage explorations, the investigation of underwater missiles, and countless

other areas of research.

I. THE PROBLEM

Statement of the problem. The purpose of this study is (1) to consider the historical background and present status of underwater cinematography; (2) to examine the photographic conditions found under water; (3) to consider the optics of underwater photography; and (4) to discuss the various pieces of equipment designed to operate under water.

Importance of the problem. To date, no study of this kind has been made at The University of Southern California or at any other university, to the writer's knowledge. The importance and implications of submarine photography to the United States Navy, and to oceanographers warrants this investigation in terms and within the scope of this thesis.

Organization of the remainder of the thesis. Chapter II will trace the history and present status of underwater cinematography. Chapter III will be concerned with photographic conditions under water. Chapter IV will be devoted to the optics of underwater photography. Chapter V will examine the equipment designed

to operate under water. Chapter VI will be a summary of the study and will present conclusions drawn from the foregoing data.

II. DEFINITIONS OF TERMS USED

Dissolved matter. Matter which, due to the solvent property of water, is dissolved, thus reducing the optical transparency of the medium.

Suspended matter. Particles of organic or inorganic matter held in suspension by water due to its density and viscosity.

Nuisance light. A haze that originates in the scattering of light by the water and suspended matter between the camera and the subject. It tends to mask detail and contrast; as the distance becomes greater, the haze becomes brighter, compared to the brightness of the subject.

Water haze. The equivalent of nuisance light.

Haze light. The equivalent of nuisance light.

Photo-diver. A cinematographer or cameraman who operates a camera under water, utilizing a suitless

diving helmet or a self-contained compressed air diving mask.

III. REVIEW OF RELATED STUDIES

There have been no other studies here at the University of Southern California which deal with, or are related to this study.

IV. METHOD OF PROCEDURE AND SOURCES OF DATA

The method of this investigation has been the examination of the literature concerning underwater cinematography currently available, correspondence with designers and users of underwater equipment, and personal interviews with others interested in underwater cinema equipment.

CHAPTER II

A BRIEF HISTORY AND PRESENT STATUS OF UNDERWATER CINEMATOGRAPHY

I. HISTORY

Someone once said, "There is nothing really new under the sun," and this is certainly true about undersea cinematography. Since there has been very little written on this phase of photographic history, most people assume that it is a rather new development, but this is a false assumption, for men have been photographing underwater life since late in the nineteenth century. Not all of their attempts have been successful, but with each failure a new lessons was learned, and the succeeding descents always proved more rewarding. Today, underwater cinematography is rapidly being recognized as a definite part of the photographic art and not merely an amateurish hobby or a freak.

The year 1893[1] marks the birth of underwater

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[1] Henry S. Moncrief, "Historical Development in Underwater Photography," Photographic Society of America Journal, 17:11-26, November, 1951.

photography. In that year, Dr. L. Boutan, a French biologist, enclosed a fixed-focus camera in a monstrous water-tight copper box and took some recognizable pictures of still objects beneath the surface of the water. Seven years later, in 1900, he made the first successful underwater night pictures by using crude arc lamps which consisted of blowing magnesium over an alcohol lamp burning in a submerged bell jar.[2]

In 1908, Mr. C. Williamson,[3] of Norfolk, Virginia, proposed and illustrated an apparatus designed to photograph beneath the surface of the sea at a much greater depth than was ever before attempted. His device was a steel sphere, large enough for a man to get inside and operate a camera. It was to be connected to the bottom of a barge by a collapsible steel tube. Illumination was to be furnished by several arc lamps attached to a cross beam and lowered beneath the surface from the barge.

Five years later, Williamson and his son successfully operated this sphere on the bottom of Hampton

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[2] Ibid., p. 26.

[3] Scientific American, 109:6-237, July, 1913.

Roads Bay, Virginia, and obtained some rather satisfactory still and motion pictures. From the experience gained from this venture, Williamson photographed what was probably the first photoplay utilizing underwater sequences, "Twenty Thousand Leagues Under the Sea," in the year 1915.[4]

Early in 1917, Mr. H. Hartman,[5] a New York civil engineer, invented an electric camera rig for deep sea photography. It consisted of three steel drums mounted one above the other and supported by a bridle which was connected to a cable leading to a ship's boom. The top drum contained an electrically-driven propeller which rotated at 400 RPM and permitted the rig to revolve, taking pictures in all directions. The next drum contained a still camera which had shutter and focus, and tilting was done electrically from the deck of the ship. The last drum was the light source which was nitrogen gas under pressure.

Little is known as to the use or results obtained

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[4] E. R. F. Johnson, "Undersea Cinematography," Journal of the Society of Motion Picture and Television Engineers, 32:3-1, January, 1939.

[5] "An Electric Camera for Deep Sea Photography," Scientific American, 116:4-483, May, 1917.

from this equipment, which was by far the most unique design yet utilized.

In 1917, Dr. W. H. Langley, who is recognized as the father of underwater photography in the United States of America, produced some usable underwater pictures and his success encouraged others to experiment further. Dr. Langley conducted most of his experiments at the Carnegie Institution Station in Dry Tortugas, using a 4x5 Auto-graphlex camera enclosed in a heavy brass box. This camera, although heavy and clumsy, had the focus, speed, and trigger available to the diver and was a great advancement in underwater camera design.

Dr. Langley continued his experiments and in 1923 he obtained the first underwater color pictures, called Autochromes. Because these pictures required very long exposures, subject matter was limited to still life.[6] By 1926, he was able to obtain color photographs of fish by a unique and highly dangerous process which involved the ignition of a pound of magnesium powder on the surface of the water with a reflector over the top, synchronized with the camera. This set-up was confined to shallow water--ten to fifteen feet--and was

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[6] Moncrief, op. cit., p. 26.

moderately successful using an exposure of one-twentieth of a second.

After several experimental years, Dr. Paul Bartsch,[7] of the Smithsonian Institution, designed a successful underwater motion picture camera in 1927. As there is no authoritative information on the first underwater motion picture camera, it is assumed that Dr. Bartsch's camera holds this distinction. At any rate, it was the first motion picture camera that could be focused under water and operated by a diver rather than from the inside of a bell or sphere.

Around this same time, Arthur C. Pillsbury,[8] scientist, inventor, and lecturer, constructed both an underwater still camera and motion picture camera. Successful underwater pictures to illustrate his lectures were taken. His motion picture cameras continued in the heavy class, weighing about one hundred seventy pounds.

The American Museum of Natural History conducted an expedition to Haiti in 1928[9] to study fish and their

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[7] Ibid., p. 27.

[8] Loc. cit.

[9] William Beebe, Beneath Tropic Seas (New York: G. P. Putnam's Sons, 1928), p. 211.

habits. An underwater motion picture camera compartment was constructed at the museum under the direction of Messrs, William Beebe, Mark Barr, and John Tee-Van. A 35 mm. DeVry motion picture camera was selected, partly because of its shape, and was enclosed in a brass water-tight box with a glass port. The rear opened to allow insertion of the camera and was clamped closed by ten screw clamps. It was water-tight, having no openings of any kind, even the trigger, the only underwater control being the trigger which was operated by pressing a rubber torsion disk. As there were no outside adjustments or controls, the camera had to be returned to the surface for re-winding and for lens and focusing adjustments. In spite of these handicaps, some satisfactory footage was obtained, as well as practical revisions for future underwater camera designs.

E. R. Fenimore Johnson,[10] of Ardmore, Pennsylvania, became interested in underwater photography in 1928 and designed a cylindrical water-tight housing for his Eyemo motion picture camera. In this first apparatus, only the trigger was available to the diver and very little usable footage was obtained.

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[10] Johnson, *op. cit.*, p. 2.

Johnson continued his development of an underwater movie camera under the name of the Mechanical Improvements Corporation (later changed to Fenjohn) and put to good use the experience gained from his first underwater attempt.

In 1929, Dan Clark, A. S. C.,[11] a cameraman for the Fox Studios, designed and built a wooden diving bell in which he photographed some underwater scenes of horses swimming for a Tom Mix picture. The footage obtained was quite usable, although Mr. Clark was nearly drowned when the horses became excited and nearly kicked his frail wooden bell to pieces.

In 1931,[12] Mr. Johnson's company built a cast aluminum housing for a Bell and Howell Eyemo, which was used by the Vanderbilt-Gilks Oceanographic Expedition of 1931. Some of the footage from this expedition was included in the commercial motion picture production by Vanderbilt, called "Devil's Playground."

The Johnson-Smithsonian deepsea camera housing

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[11] Loretta K. Dean, "At the Bottom of the Sea," American Cinematographer, 10:5-34, August, 1929.

[12] Alfred L. Gilks, A. S. C., "Undersea Photography with an Eyemo," American Cinematographer, 12:6-9, October, 1931.

was constructed in 1933.[13] Two features were ingenious and interesting: on the optically flat quartz window that lay on a lapped steel surface, no gaskets were used; a perfect, non-leaking fit was accomplished when the housing was closed through the use of a soft copper gasket, which flowed under pressure when the housing was closed. This camera was successfully lowered to a depth of 3,000 fathoms on the first descent, but, unfortunately, on the second, the suspending wire parted and the camera was lost.

Mechanical Improvements Corporation,[14] in 1939, produced an underwater motion picture camera with an Akeley mechanism which embodied many new features not found on previous cameras. It included an electric power-drive, a rotatable polarizing plate, interchangeable filters, and a choice of three lenses, all within the housing and operable by the diver. This was a great step forward in the functional design of the modern undersea movie camera.

At this same time, a water-tight housing for both the Weston model 650 exposure meter and an underwater

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[13] Moncrief, op. cit., p. 27.

[14] Ibid., p. 26.

rangefinder was developed by the Mechanical Improvement Company to quickly determine the correct exposure and camera-to-subject distance beneath the surface of the water.

In France, Jean Painleve and Commander Le Prieur,[15] of the French Navy, got together and formed the Club des Scaphondriers (Diver's Club), in 1935. Painleve and club members did much to develop underwater cinematography and the techniques evolved had important consequences during World War II. Painleve has produced several films on underwater life, using both the diving and the aquarium technique. Among his works are "L'Hippocampe" (The Sea Horse), "Prodeces la Promenade au Jardin," "Les Oursins" (Sea Urchins), and "La Pienore" (The Octopus).

A very colorful personality in the person of Captain John D. Crary entered the scene in 1935.[16] He constructed an underwater motion picture camera using a DeVry "A" newsreel camera and took some hair-raising adventure-type footage which was sold to various motion

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[15] John Maddison, "The World of Jean Painleve," <u>Sight and Sound</u>, 19:6-249, August, 1950.

[16] Moncrief, <u>op</u>. <u>cit</u>., p. 26.

picture companies.

In 1939, Drs. E. Newton Harvey and Edward R. Baylor[17] designed a pressure chamber with two windows, one for a 16 mm. motion picture camera, the other for a light, and recorded some small organisms at a depth of from 500 to 700 fathoms.

Dr. W. Maurice Ewing,[18] of Woods Hole Oceanographic Institution, designed a very successful underwater camera in 1941. He used a German Robot still camera in a water-tight case on a pole some twelve feet long. Flash bulbs attached to the pole were set off upon contact with the bottom. The camera was not joined with the boat in any way but returned to the surface after taking the pictures upon automatically dropping her ballast. Very successful pictures of limited areas were taken down to 2,700 fathoms.

Using the Ewing camera, Frank Haymaker,[19] of the Scripps Institute of Oceanography, photographed the

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[17] Ibid., p. 27.

[18] Ibid., p. 26.

[19] Francis P. Shepard, "Terrestial Topography of Submarine Canyons Revealed by Diving," Bulletin of the Geological Society of America, 60:10-1597, October, 1949.

submarine canyons off La Jolla, California. He obtained several good photographs despite the fact that photographic conditions were not the most satisfactory.

During World War II,[20] the navy produced several training films which were photographed under water with some success. A standard 35 mm. camera was encased in a bulky water-tight housing without external controls and was used successfully only with difficulty. Mr. E. R. F. Johnson was recalled to active duty to coordinate and develop the technique necessary to produce satisfactory underwater motion pictures.

Around the latter part of 1948, William F. Dudley Whitman,[21] of Miami Beach, Florida, designed an unusual underwater motion picture camera housed in lucite. Successful underwater pictures taken with this camera were published in *Life* magazine.

The latest and most advanced professional underwater motion picture camera was introduced in 1950 by the Eclair Camera Company of France. This camera, the

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[20] R. R. Conger, "U. S. Naval Underwater Cinematography Technique," *Journal of the Society of Motion Picture and Television Engineers*, 55:6-627, December, 1950.

[21] Moncrief, *op. cit.*, p. 26.

Aquaflex,[22] is a self-contained motor-driven, underwater motion picture camera with external lens controls and automatic interior pressurization. This professionsl 35 mm. submarine camera of revolutionary concept is entirely independent of air supply and electric cables leading to the surface.

Professor John F. Storr[23] tried his hand at underwater cinematography in 1951. He designed and had constructed an aluminum housing for his Bolex H-16 motion picture camera. His camera was equipped with an Yvar 16 mm. f/2.8 lens. He filmed undersea life off the coast of the Bahamas and obtained quite satisfactory results.

II. PRESENT STATUS

The most obvious and well-known application of underwater cinematography today is in Hollywood productions. Underwater sequences have been effectively used in the photoplay as early as 1916, when they were used in the picture, "Twenty Thousand Leagues Under the Sea."

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[22] Conger, _op. cit._, p. 628.

[23] John F. Storr, "Filming Fifty Feet Down," _International Photographer_, 23:7-10, July, 1951.

Today the tendency of producers to show what happens under water as a part of their stories has grown vastly, to say nothing of pictures having the principal parts of their plots based on action allegedly taking place there. The recent picture, "Frogmen," directed by Norbert Brodine, was an excellent example of the effective use of underwater scenes to reveal the action taking place below the surface of the water.

There have been innumerable other productions employing underwater scenes. Among them were "Sunset Boulevard," "Red Sea Adventure," and "Maru Maru." Walt Disney has recently revealed that he will produce a new "Twenty Thousand Leagues Under the Sea" in color.

He intends to utilize undersea footage that will be filmed all over the world and estimates it will take a year to complete this film.

In France, Jacques Cousteau recently produced an exciting film titled "Carnet de Plongee" (A Diver's Log).[24] The film was photographed in Agfa Color and is in three parts. The first part shows an ancient submerged Greek temple off the Tunisian coast near Mahdia; the second

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[24] French Films Information, Bulletin No. 9, April, 1951, p. 8.

part reveals the spectacle of the coral reefs shown off by artificial light; and the last part shows the dramatic undersea episodes of tuna fishing off the North African coast.

Universal-International Pictures has recently released two short subjects entitled "Danger Under the Sea" and "Rhythm on the Reef."[25] Both of these features were directed and photographed by Cousteau and ably demonstrate how the underwater motion picture camera has been graduated from a novelty classification.

The most effective application of underwater cinematography today is not in Hollywood but in the United States Navy. The Navy is not only producing training films photographed under water, but they are also employing the use of high speed cameras to record and study underwater explosions, the design characteristics of high speed missiles under water, and the effectiveness of various designs of ship propellers.

At Bikini, after the underwater atomic blast, the Navy discovered the only logical way to examine the underwater hull damage was to photograph it, and so a

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25 "Camera Under the Sea," U. S. Camera, 15: 3-86, March, 1952.

new use was found for this ever-expanding technique of sub-aqueous photography.

Scientists engaged in underwater research are now turning more and more to underwater cinematography to record on film the geological features of sea bottoms and the habits and characteristics of marine plant life.

For teachers, underwater films are bringing to the classroom an accurate living biology text in color.

Steel and construction companies are resorting to underwater photography to make a permanent record on film of the corrosion tendencies on various underwater structures due to the action of salt water.

Today in Southern California, there are many amateur cinematographers who have discovered the wondrous beauties of underwater life and have turned their attentions and talents to recording this mysterious world on film. The have designed and constructed excellent submarine cameras, incorporating in their designs man novel and useful features. Among these amateurs are: Bob Gottschalk of West Los Angeles, California, Al Fisher of Torrance, California, LaMar Boren of San Diego, California, and Ray McAllister of LaJolla, California.

Several companies are now offering stereo attachments for 16 mm. motion picture cameras, but at this writing, underwater stereo cinematography is limited or non-existent. The application of stereoscopy to underwater cinematography should prove to be exciting and effective, especially if the photography is in natural color.

CHAPTER III

PHOTOGRAPHIC CONDITIONS UNDERWATER

The physical qualities of water are responsible for many of the difficulties encountered in underwater photography. The purest of water is far less transparent than air; and, because it is an excellent solvent, it is rarely pure in nature, and dissolved matter profoundly affects its optical properties.[1] Then, too, water, having a greater density and viscosity than air, supports a much greater proportion of suspended matter, both organic and inorganic, and this has an even greater effect on its optical properties. The quantity and kind of dissolved matter are relatively constant for any location and, at least in sea water, are nearly the same for almost all areas where underwater pictures can be taken. Suspended matter, on the other hand, is highly variable both at different locations and at the same location with varying season and weather.[2] It is

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[1] E. R. F. Johnson, "Undersea Cinematography," Journal of the Society of Motion Picture and Television Engineers, 32:1-3, January, 1939.

[2] Ibid., p. 2.

the quantity of suspended organisms and particles that fully determine whether or not satisfactory pictures can be taken at a particular place or time.

The scattering of light by the water and the suspended matter form what is commonly called water haze or "nuisance light." It is quite analagous to aerial haze but, being much more intense, its effect shows up in pictures of an object only a few feet away, rather than a matter of miles.[3] Its effect to the camera is a uniform exposure over the whole picture, which tends to mask detail and contrast, as the distance becomes greater, the haze becomes brighter, compared to the brightness of the object, finally masking it completely.

A convenient measure of the water clarity is obtained by means of a Secchi disk,[4] which is simply an eight-inch white circular disk. The limiting depth to which it can be lowered in the sea and remain visible is a reliable and reproduceable measure of clarity. A rough rule for submarine photography is that adequate resolution

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[3] Ibid., p. 3.

[4] Paul M. Frye, "The High Speed Photography of Underwater Explosions," Journal of the Society of Motion Picture and Television Engineers, 55:4-414, April, 1945.

can be obtained for a camera-to-target distance equal to about one-half of the Secchi disk reading.

So far as haze light is concerned, studio tank work offers the same problem as natural settings. Mr. Johnson[5] cites one producer who found to his sorrow that even though expensive distilled water is used in a freshly scrubbed tank, the haze remains and the crisp, sharp pictures desired were not obtainable.

The fact that this nuisance light is present even in distilled water that has stood long enough to be free of air bubbles indicates that the origin of much of it must be molecular scattering by the water itself. Therefore, according to the Raman-Einstein-Smolchowski theory, it should be almost completely polarized.[6]

When photographing by sunlight, the first factor to be considered is the overall reduction in the intensity of light. This varies greatly with conditions, but under average conditions the limiting depth is from twenty-five to forty feet. Fortunately, the largest percentage of interesting marine life and human activity is to be found within this range. At greater depths

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[5] Johnson, <u>op</u>. <u>cit</u>., p. 4.

[6] <u>Loc</u>. <u>cit</u>.

photographic subjects become more scarce and difficulties are materially increased.

A further complication is added by the fact that water does not absorb different colors equally. Sea water is most transparent in the blue-green region between 4400 and 5400 A° and red light is quickly absorbed. This filtering action of water makes a true monochrome rendering of subjects difficult, and has an even greater effect on photography in natural colors.

Dr. William Beebe[7] describes the spectral quality of the sea during a dive in his Bathosphere off Bermuda in 1934:

> On this and other dives I carefully studied the changing colors, both by direct observation and by means of the spectroscope. Just beneath the surface the red diminished to one-half its normal width. At twenty feet, there was only a thread of red and at fifty feet, the orange was dominant. This, in turn, vanished at fifty feet. At 300 feet the whole spectrum was found to be dimmed, the yellow almost gone and the blue appreciably narrowed. At 350 feet I should give as a rough summary of the spectrum 50% blue violet; 25% green, and an equal amount of colorless pale light. At 450 feet, no blue remained, only violet and green too faint for naming. At 800 feet there was nothing visible

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[7] O. E. Hulbert, "On the Penetration of Daylight into the Sea," <u>Journal of the Optical Society of America</u>, 7:22-408, July, 1932.

but a narrow line of pale grayish-white in the blue-green area.[8]

Objects at a distance do not appear to be the same color to a diver as when they are close by. A diver's vision fades out in a misty blue-green haze. Color film, however, accentuates this effect, making the background an unnaturally intense blue-green.[9]

Mr. Floyd Crosby who, in 1936, shot the first technicolor underwater footage for Pioneer Productions, made this observation about color rendition under water:

> . . . and this matter of color balance brought up a very interesting psychological point. Under water, everything is definitely tinged with the blue-green of the water. But after one has been down a few minutes, he is no longer conscious of this coloring. On the screen, however, if the scene was printed exactly as your eye (the camera) saw it underwater, that blue-green is objectionable. I suppose it is due to the relatively confined area of the screen; at any rate, the eye does not accommodate itself to this coloring on the screen as it does under water. Accordingly, the print has to be balanced, or rather unbalanced, toward the red, if the audience is to accept it as natural.[10]

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[8] William Beebe, Beneath Tropic Seas. New York: Harcourt, Brace, and Company, 1934, p. 119.

[9] Johnson, op. cit., p. 5.

[10] Floyd Crosby, American Cinematographer, 17: 9-376, September, 1936.

For the best results when filming with existing light, it is recommended to limit the shooting time to between 10:30 AM and 3:30 PM in bright sunlight.[11] On overcast days the resulting pictures will be so flat and "muddy" that they will be found useless.

It is best to shoot where the bottom is light so as to reflect some light upwards into the shadows. If possible, one should shoot most of the scenes either shoreward or have the camera pointed sideways along the shelving part of the beach. Shots made with the camera pointing straight out to deep water usually have a dark background, and nothing to give them depth or perspective.[12]

Light rays passing into water through the surface are bent until they travel nearly straight down, so by natural illumination underwater subjects are inclined to be overly contrasty with highlights on top and dense shadows underneath. Mr. Johnson[13] tried to relieve this situation with reflector boards but found that

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[11] Johnson, op. cit., p. 4.

[12] Thomas Tutweiler, "Making Movies Underwater, American Cinematographer, 23:8-360, August, 1942.

[13] Johnson, op. cit., p. 5.

boards large enough to help at all had so much water resistance that even in slack water they were difficult to handle and with any current it became impractical either to set them or keep them in position. Shadows can be relieved to a certain extent by the use of artificial lights. Reflectors must be small and highly efficient or they become unmanageable in any current. In using lights, it is necessary to exercise extreme care in placement; otherwise, haze light makes the lamp beam visible. Since most of the energy from an incandescent light is in the red end of the spectrum, in which region water has its greatest absorption, the power requirements are much greater than for equivalent illumination at the surface.

The clear waters most favorable for undersea photography are found in tropical bays, lagoons, and other sheltered areas where horizontal visibility is greatest. These warm, still waters are also attractive to large and, oftentimes, potentially dangerous fish.

The photo-diver's working location is usually on or near the sea bottom where there are moray eels, octopuses, and other fearsome-looking creatures. Usually, these fish do more to enhance the picture than to hinder

the photographer.

> . . . The underwater crew encountered quite a few manta or sting rays, several large sharks, many barracuda (one measured five and one-half feet in length), and three moray eels, one having a head five inches wide. The bat-like appearance and the thrashing, barbed tail of the fast moving manta rays made the crew uneas although none attempted to attack . . .[14]

Oddly enough, the photo-diver's greatest enemy is the coral and not the fish. After prolonged exposure to water, the diver's skin becomes soft and is easily cut on jagged coral. These wounds take six weeks or longer to heal and leave pronounced scars.[15]

The compressed air diseases are another source of danger to the photo-diver when using the suitless diving rig or the now-popular self-contained Aqualung unit. Hence, it cannot be too highl stressed that the photo-diver, for his own safety, must be completely familiar with his equipment and must be in excellent physical and mental health if he is to avoid mishap while photographing under water.

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[14] R. R. Conger, "U. S. Naval Underwater Cinematography Technique," Journal of the Society of Motion Picture and Television Engineers, 55:6-629, December, 1950.

[15] Ibid., p. 630.

CHAPTER IV

OPTICS OF UNDERWATER PHOTOGRAPHY

It is general practice in underwater photography to use ordinary cine lenses computed for use in air and protected by a glass window. This naturally introduces a water-air boundary which affects the focus and correction of the lens. Objects under water appear nearer and larger both to the eye and to the camera. This effect on focus was computed[1] and it turned out that the ratio of the air focus to the underwater focus is equal to the index of refraction of air with respect to water. The index varies with the salinity and temperature of the water, but the value 0.750 may be used for all conditions with negligible error. Hence, to focus on an object at any distance under water, the same lens extension is required as for an object at three-fourths of that distance in air.[2]

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[1] E. R. F. Johnson, "Undersea Cinematography," Journal of the Society of Motion Picture and Television Engineers, 32:1-3, January, 1939.

[2] Ibid., p. 4.

The presence of the water-air boundary in front of the lens also introduces spherical and chromatic aberration. Fortunately, if the plane of the window is perpendicular to the axis of the lens, they are both too small to require correction. In tank work, any attempt to position the camera other than normal to the plane of the window will result in objectionable aberration.[3]

Mr. Thomas Tutweiler[4] points out that refraction also narrows down the lens-angle considerably, so that an underwater scene filmed with a 16 mm. camera equipped with a 25 mm. lens looks on the screen as though it had been made with a two-inch lens. He recommends the best way to get around this is to use a wide-angle lens such as the 15 mm., as it will give one underwater about the same coverage as one would expect from the 25 mm. lens on land.

As it was pointed out in the previous chapter, water does not absorb different colors equally, making it difficult to record an underwater subject in true

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[3] Ibid., p. 4.

[4] Thomas Tutweiler, A. S. C., "Making Movies Underwater," American Cinematographer, 23:8-360, August, 1942.

monochrome. In color photography, compensating filters can be used to correct for the spectral quality of light at any given depth. Mr. Johnson[5] points out that theoretically a different filter would be required for every depth and the same would be true for different distances from the camera to the object. Thus, if an object six feet deep is being photographed at a range of six feet, a compensating filter correct for twelve feet of water would be required.

In 1936, when Floyd Crosby[6] experimented with Technicolor under water, he used a Wratten 86A filter to filter out some of the blue-green, which was felt to be objectionable.

The greatest *bête noire* of the underwater photographer is haze, or "nuisance light."

> . . . It was felt that water haze, like aerial haze, should consist principally of light in a limited spectral region and that a color filter would eliminate much of it. With this in mind, we conducted a series of experiments with an underwater spectrograph. Tank tests showed great improvement when a Wratten Aero No. 2 filter was used.[7]

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[5] Johnson, *op. cit.*, p. 5.

[6] Floyd Crosby, *American Cinematographer*, 17: 9-376, September, 1936.

[7] Johnson, *op. cit.*, p. 5.

The chief objection in black and white photography to the use of colored filters to eliminate haze is the fact that water is most transparent to the blue-green region of the spectrum; but this is also the region of maximum intensity of the haze light, so, by eliminating it, the most efficient photographic light is also lost.[8]

Through the use of polarizing screens, it is possible to eliminate a greater part of the "nuisance light" than by any other means. Their use requires an exposure increase of from about two to four times. Unfortunately, the haze light is not completely polarized so that, while the distance at which satisfactory pictures can be obtained is extended, there is still a very definite limit.[9]

Probably the most advantageous feature of this method of eliminating haze light is that polarizing screens are almost spectrally neutral.[10] They do not distort the monochrome rendering nor do they eliminate the most useful portion of the spectrum as does a yellow or red filter. This spectral neutrality further

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[8] *Ibid.*, p. 4.

[9] *Loc. cit.*

[10] *Ibid.*, p. 6.

makes possible haze elimination when using color film, but at present, the speed of color film does not permit the use of both a compensating filter and a polarizing screen under normal conditions.

CHAPTER V

UNDERWATER PHOTOGRAPHIC EQUIPMENT

The history of underwater cinematography, sketchy as it may be, clearly illustrates the fact that there is much more to submarine photography than just merely enclosing a motion picture camera in a water-tight case. As with any creative work, there were months and years of patient work, sweat, and disappointments before a successful and efficient underwater motion picture camera was developed.

Having outlined the technical and practical difficulties confronting the underwater cinematographer, we shall now consider briefly the ideal attributes of apparatus required to meet these difficulties and the practical equipment developed by the professional and the amateur to operate successfully and effectively under water.

Mr. E. R. F. Johnson[1] points out several design

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[1] E. R. F. Johnson, "Undersea Cinematography," Journal of the Society of Motion Picture and Television Engineers, 32:1-6, January, 1939.

considerations necessary for the efficient and successful operation of an underwater motion picture camera.

The returning of equipment to the surface for adjustments of stop or focus or change of filter is wasteful of time. Therefore, the first requirement of underwater photographic equipment is that all adjustments may be made quickly and conveniently undersea by the photo-diver.

The fact that water is a far less yielding medium that air, dictates other requirements. A camera that would be quite stable in a twenty mile wind might easily be thrown over by even a two mile current. For this reason, a camera should be light enough for ease of carrying, but heavy enough to be stable. The addition of fins, similar to those of an airplane, are quite effective in minimizing the sway and billow often encountered in shallow water work.

Man becomes a clumsy, slow-moving creature when he works below the surface of the water. It is therefore important that any couplings that must be made should be large and distinct, and all controls and calibrations should be visible and operable from one position.

Even after short submergence, the photo-diver's skin becomes softened and easily cut by things that would not do so on the surface. For this reason, everything must be made smooth, with no sharp edges.

Direct focusing is difficult, if not impossible, and therefore accurate focus calibrations of lenses is a necessity.

The construction of face masks and helmets, plus the fact that it is difficult for a diver to remain perfectly still, makes it necessary that view-finders be corrected for an eye position well back of the port. Because of the reduced illumination under water, it is important to have a large, brilliant image view-finder.

Today there are several professional underwater motion picture cameras available which are designed to give the underwater cinematographer an instrument possessed of the greatest possible flexibility and convenience of operation.

The Fenjohn Underwater Photo and Equipment Company[2] of Ardmore, Pennsylvania, is the only company known

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[2] Henry S. Moncrief, "Historical Development in Underwater Photography," Journal of the Photography Society of America, 17:11-28, November, 1951.

to the writer who is manufacturing underwater cameras in quantity in the United States. The camera presently in production is built around a 16 mm. Bell and Howell motion picture camera with a fifty foot film capacity. The camera is equipped with an f/1.5 13 mm. Elgeet wide-angle lens which mounts four filters. It is electrically operated by self-contained batteries, and has a useful run of 1,000 feet at sound speed. The aperture, focus, filter, and speed settings can be made under water by the diver, the first three settings being visible through the large, brilliant image view-finder. The trigger is conveniently placed on the right handle and is easily operated by the thumb. The water-tight housing is cast aluminum machined to a fine tolerance, and the entire camera weighs but twenty-one pounds in air, and only three and three-fourths pounds when under water.

This camera is now being used by the navies of two countries as well as by many amateurs and scientists. Its light weight, ease of operation, and rapid reloading (twenty-five seconds) make this an ideal camera for the undersea cinematographer, whether a professional or an amateur.

Another excellent professional undersea motion

picture camera available today is the Aquaflex, manufactured by the Eclair Company of France.

The Aquaflex is primarily an Eclair Camerette, which is contained in an underwater housing with external controls to operate the lens diaphragm, focus, and starting switch. The camerette is driven by a 6-8 volt, 7 Ampere motor, which is powered by four batteries. It is supplied with 28, 40, and 75 mm. coated f/2 Kinoptic lenses. However, these are not interchangeable under water. Small lights are located in the Aquaflex blimp to illuminate the interior exposure meter, film speed tachometer, internal pressure differential gauge, and the film footage counter located on the 400 foot film magazine. These lights go off when the starter switch is turned on to give the motor maximum voltage. The Camerette utilizes a reflex optical system so that the diver-photographer views the image through the taking lens. The shutter may be set at any desired opening from 200 to thirty-five degrees, thus presenting an exposure range from one-fourteenth of a second at eight

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[3] R. R. Conger, "U. S. Naval Underwater Cinematography Technique," Journal of the Society of Motion Picture and Television Engineers, 55:6-631, December, 1950.

frames a second to 1/413 second at forty frames a second.

The front section of the Aquaflex contains the plastic photographing port, the control gears, and camera mount, the batteries and wiring, the pressure gauges and exposure meter, plus all the necessary mechanisms for controlling the Camerette under water. The rear section covers the 400 foot film magazine, contains the three smaller viewing ports, and seals the camera. The Aquaflex is delivered with two 400-foot film magazines, three one-liter compressed air bottles, and other accessories, plus the necessary filling adapters and camera case. The detachable wings and vertical rudder aid greatly in transporting and stabilizing the camera under water. With them, it is possible to guide the camera with one hand, using the other to aid in swimming. The camera wings actually act as a planing surface, so that the photo-diver can sight on his target through the view-finder, kick his flippered feet, and guide himself by tilting and banking the camera in a manner similar to a plane flying through the air. The Aquaflex, complete, weighs about 107 pounds in air, but can be adjusted to have either positive, negative, or neutral buoyancy under water.

The Aquaflex is by no means leakproof,[4] but the supply-demand type compressed air valve is so regulated that the housing contains about three pounds per square inch over the sea pressure at any depth the camera may be taken. The camera air supply is carried in a charged cylinder, compactly arranged on the underside of the Aquaflex blimp. As the Aquaflex is descending, the demand valve increases the interior pressure to equal the depth pressure plus three pounds per square inch. On the ascent, the demand valve closes and excess air pressure escapes through the relief valve. The three pounds per square inch interior-exterior pressure difference should always remain the same and is visible on a gauge located in the Aquaflex blimp.

Because the Aquaflex is a completely free and mobile underwater unit, the photo-diver must be equipped with self-contained or free diving equipment. The French Aqualung[5] has been found to be the best and most completely automatic compressed air self-contained diving unit. It has a separate mouthpiece breathing hose with which the "Squale" face mask may be used. This is an

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[4] _Ibid._, p. 631.

[5] _Ibid._, p. 632.

ideal piece of equipment as it leaves the photo-diver's hands free to operate the camera, and his mind is free to concentrate on his photographic work.

Both the Aquaflex and the Aqualung operate on the same automatic supply-demand principle. The greater the water pressure, the greater the pressure of air supplied to both the diver and the Aquaflex. Both the camera and diver are of neutral buoyancy so that the photographer, with the aid of swim fins on his feet, is able to swim with the camera in any direction or to any depth down to approximately two hundred feet.[6]

Mr. Scotty Welborne,[7] a hollywood cinematographer, has designed and built an underwater camera around a Bell and Howell Eyemo. The water-tight housing was constructed of steel in the shape of a sphere. The motor, focus, stops, and lens turret are operated electrically by self-contained batteries. The camera weighs ninety pounds in air and is equipped with a compressed air system for internal pressurization.

In the study of underwater explosions by the navy

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[6] *Ibid.*, p. 632.

[7] Scotty Welborne, "New Underwater Camera," *International Photographer*, 23:3-10, March, 1951.

at the David Taylor Model Basin, three high speed cameras were used. One was the Eastman Hi-Speed, the second was the 35 mm. Fastax;[8] and the third was a rotating-mirror frame camera of Naval Ordnance Laboratory design.

The Naval Ordnance Laboratory camera was designed by S. J. Jacobs and A. A. Klebba[9] and is essentially a modified Bowen camera. The image is focused on a spinning mirror which has the focal axis of the taking lens system for its axis of rotation. The plane of rotation is forty-five degrees to this axis. One hundred framing lenses provide one hundred pictures. With the mirror revolving at a rate of 18,000 RPM, one hundred pictures can be taken at the rate of 30,000 frames per second.

The Naval Ordnance Laboratory camera was used to photograph underwater explosions at a depth of two miles, while the Eastman camera was used at a depth no greater than 1,000 feet.[10]

Of the cameras designed by the amateur cinema-

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[8] Paul M. Frye, "The High Speed Photography of Underwater Explosions," Journal of the Society of Motion Picture and Television Engineers, 55:4-414, April, 1950.

[9] Ibid., p. 415.

[10] Loc. cit.

tographer, the most efficient and successful examined by the writer was a camera designed and constructed by Mr. Robert Gottschalk,[11] of West Los Angeles, California. It must be pointed out here that this camera is far from being amateurish in construction, as it incorporates in its design all the features found to be necessary to the professional.

Mr. Gottschalk's underwater camera, which he named the Hydroscope, is designed around a Bolex H-16 16 mm. motion picture camera and is equipped with an Elgeet 13 mm. f/1.5 lens. The water-tight housing is of stainless steel with external controls to operate the lens diaphragm, focus, speed and starting switch. The camera is electrically operated by self-contained six-volt batteries. An exposure meter, built into the top of the housing, makes it simple for the photo-diver to determine the correct exposure under water.

The front section of the blimp contains the glass photographing port, recessed to form a sunshade, and the exposure meter photo-electric cell. On the bottom is located the internal pressurization system. Like the Aquaflex, the pressurization is obtained through

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[11] Personal interview, March 25, 1952.

a supply-demand type of compressed air valve. The pressure within the housing is maintained at three pounds per square inch over the sea pressure at any depth. On the right side is located the footage indicator which is fitted with a magnifying lens and may be illuminated by the operator to facilitate reading when submerged.

The photo-diver views the subject through a direct frame finder which has phosphorescent cross-wires, and which is adjustable by the operator for parallax. This type of finder allows the photographer a full vision of the entire underwater area, permitting him to be on the alert for any sign of danger or for additional subject matter.

As with the Aquaflex, Mr. Gottschalk has employed small wings to give stability to his camera, but, unlike the Aquaflex, he utilizes only the horizontal stabilizers. These wings have about a twelve degree dihedral, are adjustable as to pitch, and may be completely removed if desired. The underwater camera weight may be adjusted to positive, negative, or neutral buoyancy and the photo-diver can cause the camera to glide, dive, bank, or rise by altering the pitch of the small wings. The camera weighs sixty-five pounds in air, but as was

mentioned previously, its underwater weight can be adjusted to suit the needs of the photo-diver.

Like the majority of photo-divers today, Mr. Gottschalk uses the Aqualung in conjunction with the Squale face mask while photographing beneath the surface of the water. As was pointed out previously, the Aqualung permits the diver to descend to a depth of about 200 feet and allows him to remain under water for from one to one and a half hours, depending on depth and activity.

A camera called the Visola is now being produced in France for the amateur who wishes extreme simplicity of operation. The water-tight blimp is constructed of one-fourth inch clear plastic about a Bolex 16 mm. spring-driven motion picture camera. The only external controls available to the operator are the f stop adjustment, re-winding key, and the trigger.

The Fenjohn Underwater Photo and Equipment Company, of Ardmore, Pennsylvania, has produced a small, efficient underwater exposure meter built around the Weston Model 852.[12] The water-tight housing is of cast

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[12] Fenjohn Underwater Photo and Equipment Company, Catalog, 1952.

aluminum; the only moving part is the knob to adjust the calculator. The meter weighs sixteen ounces in air and but nine ounces under water.

The underwater motion picture cameras and associated equipment discussed in this chapter represent the latest and most efficient in design. More cameras will appear on the scene in the future, but their construction will remain similar to those in existence today, for the requirements that dictate efficient submarine camera design will always be applicable.

CHAPTER VI

SUMMARY AND CONCLUSIONS

I. SUMMARY

Having its birth in 1893, underwater cinematography progressed slowly until about 1917, when scientists, among whom were Bartsch, Beebe, and Minor, turned to underwater motion pictures to illustrate their lectures on underwater life.

Over the years, cameras of all descriptions were constructed, countless problems encountered, and numerous difficulties overcome. As a result of these long, patient, and often disappointing years, the underwater cameras of today are efficient and conveniently operable, and the technique of underwater cinematography is taking its rightful place in the field of the cinematic art.

Just as in atmospheric photography, there are certain inherent difficulties in sub-aqueous photography which must be overcome in order that satisfactory results may be achieved. The greatest problem of the photo-diver is the haze, or "nuisance light," which results from the dissolved and suspended matter present in water.

Suspended matter, both organic and inorganic, is present in fresh, salt, and even distilled water in varying degrees, depending on location, season, and weather. Dissolved matter, on the other hand, is relatively constant in any location where undersea pictures can be taken, and it greatly affects the optical properties of water.

A further complication in underwater photography is the fact that water does not absorb different colors equally. Sea water is most transparent in the blue-green region between 4400 and 5400 $\mathring{A}$ and red light is the quickest to be absorbed. This filtering action of water makes difficult a true monochrome rendering of subjects and has an even greater effect on color photography. The use of filters to correct for this spectral quality of underwater light is possible, but the results obtained do not warrant their use.

When using sunlight for illumination of underwater subjects, it has been found that the most satisfactory results are obtained where the bottom is extremely light. This tends to reduce the harsh contrast that results when there is no reflective material under the subject.

In undersea photography, it is the general practice to use ordinary cine lenses computed for use in air and

protected by a glass window. This introduces a water-air boundary which affects the focus and causes underwater objects to appear nearer and larger. Hence, it is necessary to focus on an underwater subject as if it were three-fourths that distance in air.

Refraction of light through water tends to narrow down the lens-angle considerably, so that an underwater scene filmed with a 16 mm. camera equipped with a 25 mm. lens looks on the screen as though it had been made with a two-inch lens. This effect can be overcome by using a wide-angle lens, such as a 15 mm., which will give the same coverage as the 25 mm. lens on land.

The underwater motion picture cameras of today, both professional and amateur, are efficiently designed to give maximum reliability, convenience, and speed of operation to the photo-diver. There are several practical and technical dictates that necessarily govern the efficient underwater motion picture camera design. Briefly, these are: (1) adjustments of focus, stop, filter or lens changes should be operable undersea by the photo-diver; (2) the camera should be light enough for ease of handling, but heavy enough to be stable under water; (3) the surface and edges of the housing should be smooth to preclude cutting the operator; (4) the

camera motor should be electrically operated by self-contained batteries, or, if spring-driven should be rigged for rewinding under water; and (5) the view-finder should be large, of the brilliant-image type.

There are two professional submarine motion picture cameras available today, namely, the 35 mm. Eclair Aquaflex of French design, and the 16 mm. Fenjohn, which is built around the Bell and Howell camera. Both cameras boast of all of the design features listed above and considered necessary, but the Aquaflex also includes internal pressurization, a built-in exposure meter, stabilizing fins, and a reflex-type view-finder.

Of the amateur cameras examined by the writer, the camera constructed by Robert Gottschalk, of Los Angeles, California, is most unique. It is designed around a Bolex H-16 and includes many of the excellent features found in the Aquaflex.

Associated underwater equipment necessary in submarine cinematography include: the Aqualung, which is a self-contained compressed air diving unit which allows the photo-diver complete freedom of movement; swim fins that fit on the feet of the diver and enable him to propel himself through the water with a minimum of

movement; and the water-tight exposure meter to determine the correct diaphragm setting for the existing underwater illumination, if a meter is not built into the camera housing.

II. CONCLUSIONS

During and since World War II, underwater cinematography has made its greatest strides, both technically and esthetically. Through the effective and efficient use of specifically designed and engineered underwater motion picture cameras, underwater cinematography has been elevated from the novelty classification to that of a respected part of the cinematic art.

Although Hollywood is today using underwater sequences more and more to show the action taking place beneath the surface of the water, it has yet to capitalize completely on this vast new and exciting field of cinematography. Several short subjects of foreign origin have been released recently which tend to point the way to the future trend in thrilling adventure photoplays.

We are familiar with the travelogue that conveys us, through the magic of film, to every corner of the earth, but consider the possibilities of a travelogue showing the wonders of the underwater world. Robert S.

Dietz[1] points out that we know less about the topography of the oceans than we do about the surface of the moon. An underwater film tour of the ocean floor showing the great undersea mountains, deep submarine canyons and strange and weird sea life would certainly be breathtakingly beautiful and unbelievably grotesque, particularly if it were filmed in color.

Stereoscopy is a facet of underwater cinematography that is still relatively unexplored but with a tremendous future. Presently there are several 16 mm. stereo attachments available, but there is some question as to their value, for they split the frame vertically in half and reduce the picture area considerably. A more practical, although a difficult means of achieving three dimensionality is through the application of two cameras arranged at the interocular distance with the film projected likewise by means of two projectors.

Regardless of the technical dispute, underwater stereo could prove invaluable to the navy "frogmen" in determining accurately the extent, type, and vulnerability of underwater barriers and installations. The

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[1] Robert S. Dietz, "The Pacific Floor," Scientific American, 186:4-19, April, 1952.

thought occurs to the writer that possibly an audience viewing an underwater scene, filmed in stereo, might have the uncomfortable sensation of being completely submerged in water. If this were the case, it might possibly discourage an audience from participating in such a performance!

As was pointed out in a previous chapter, underwater motion pictures have found an application in the study of underwater explosions and the performance of high speed underwater missiles. There is every reason to assume that many other applications of submarine photography will be found by the Navy as well as by scientists and engineers. Concerning camera design, the writer can only bring to mind one change or alteration to be recommended in existing cameras. This one modification would be the enlarging of film capacity to 200 feet and, if possible, to 400 feet. This suggestion is made on the basis that, in filming underwater scenes, the normal run for a single scene is about fifty feet and, at times, 100 feet. With the film capacity of 100 feet available today, this means that the photo-diver must return to the surface several times before completing a sequence. This could be costly in subject matter, as man has no control over the action or movement

of the sea life; hence, he must be prepared to shoot rapidly and on a second's notice.

In conclusion, it can be safely said that today underwater cinematography is on the threshold of its greatest development and application. Never before has man had the excellent and efficient underwater equipment to film this strange, fabulous, and unexplored world that lies beneath the surface of the seas.

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